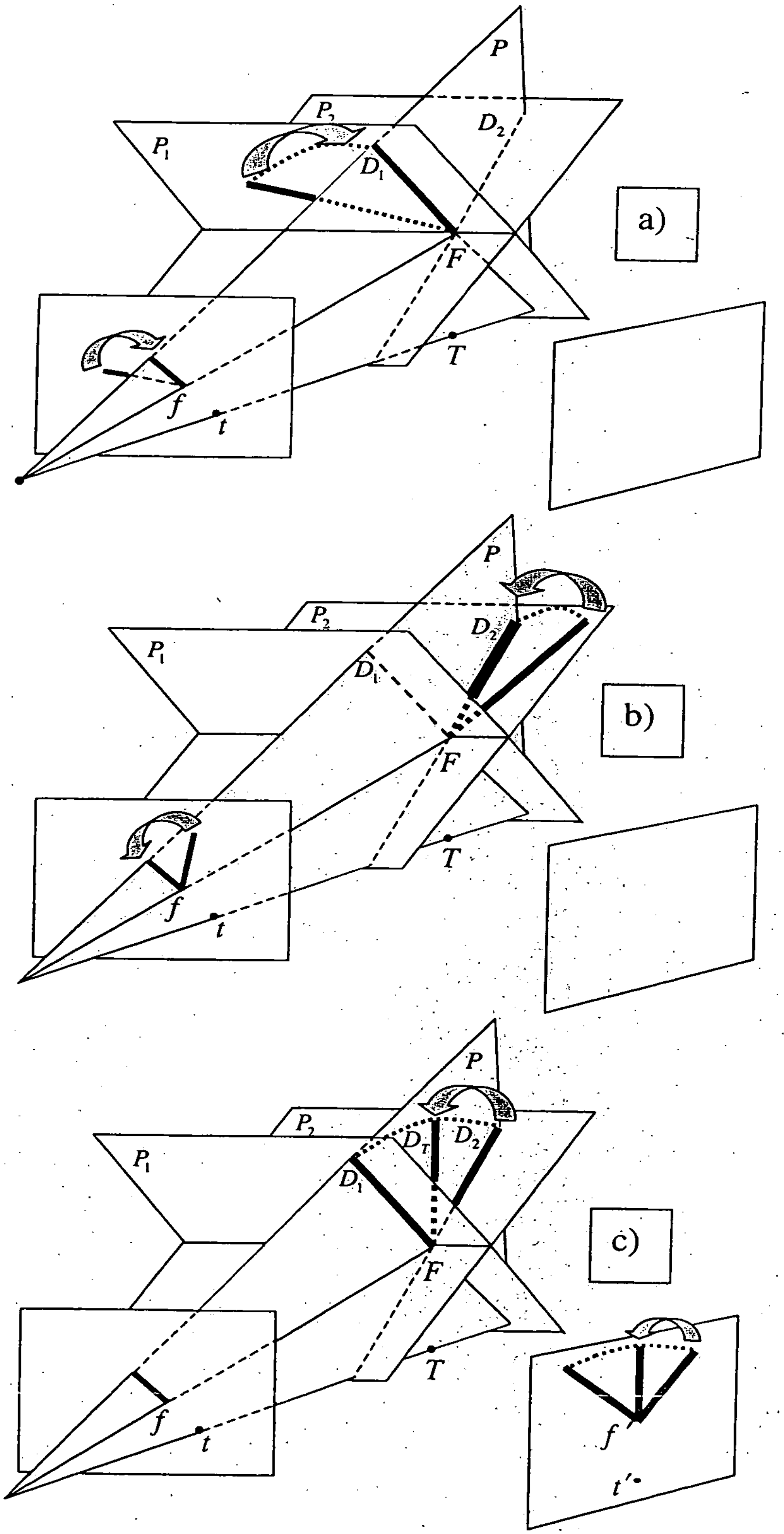

Fig. 1: Needle Placement by visual Servoing in 3 Successive Planes using 2 views

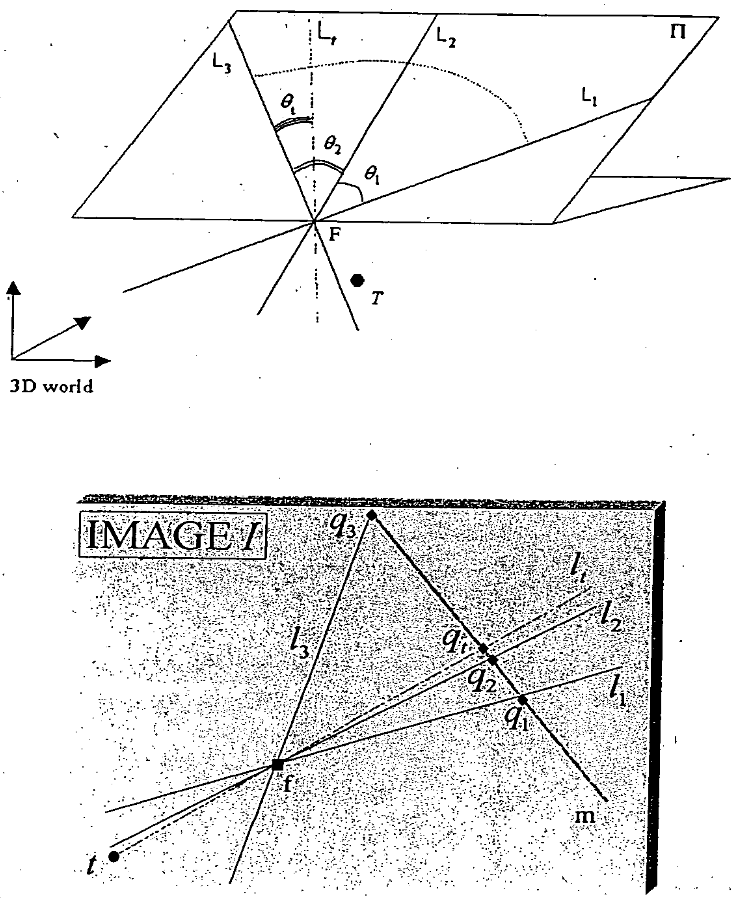

Figure 2 - Visual Servoing of a Needle in a plane using cross-ratios

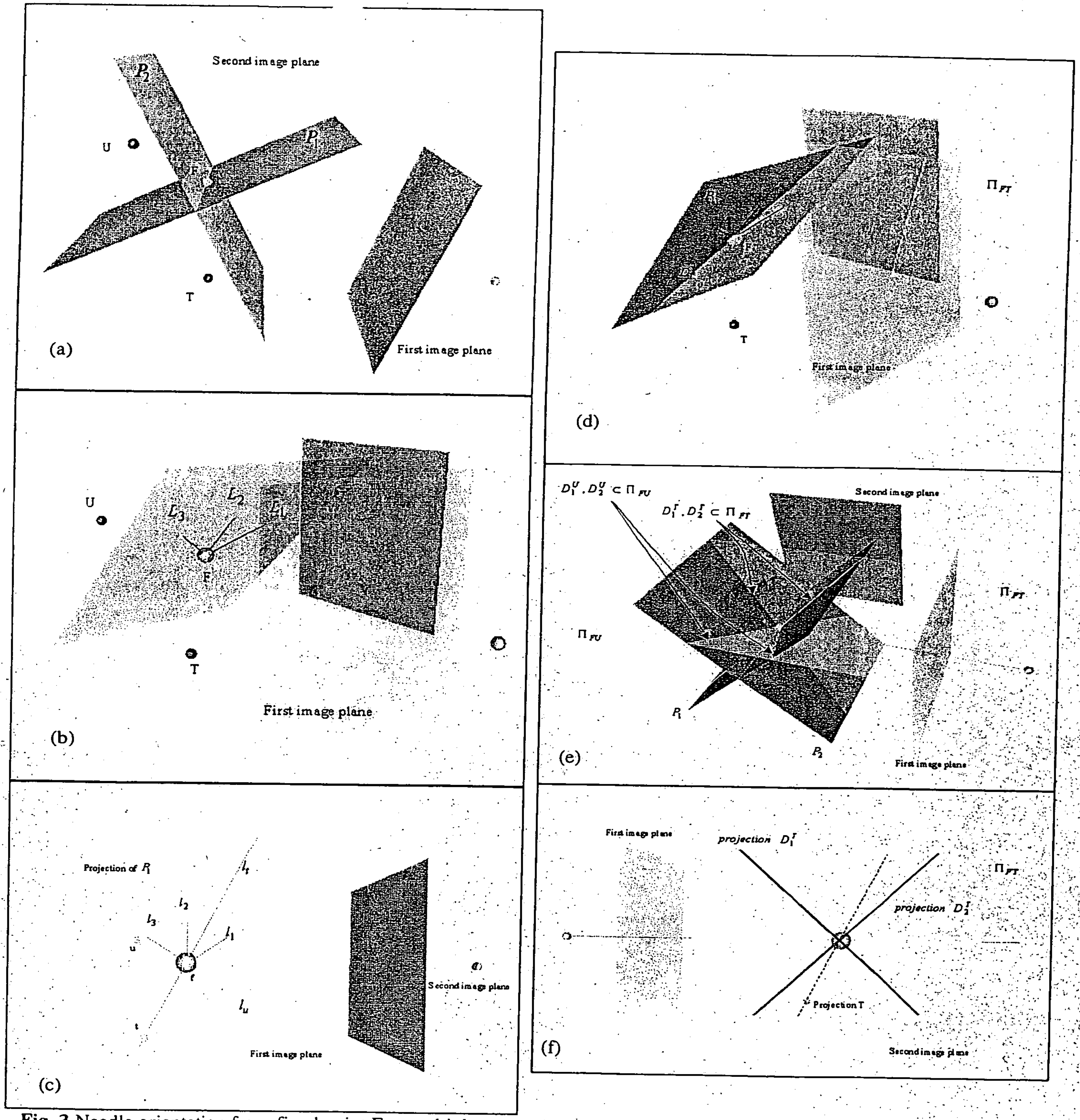

Fig. 3 Needle orientation from fixed point F to multiple targets (a) arbitrary planes P1 and P2 (b) (c) (d) visual servoing to T of needle rotating in P1 defines lines D1. (e) visual servoing in P2 defines D2. D1 and D2 give viewing plane Π_{FT}. Similar approach gives Π_{FU}. (f) visual servoing in second image plane of needle rotating in Π_{FT}. The resulting orientation of the needle is along (FT). Similar approach to be applied for Π_{FU}.

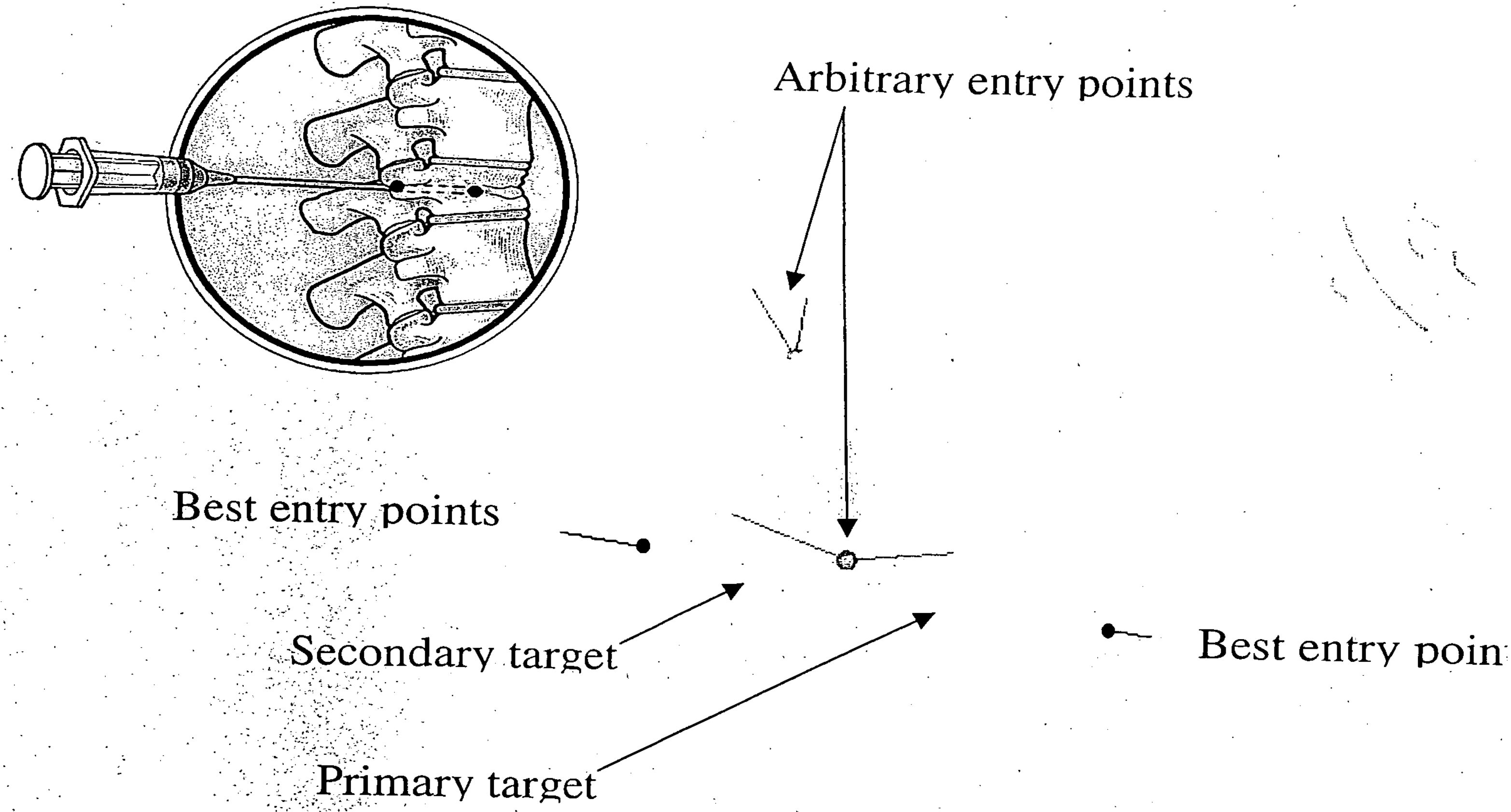

Fig. 4 Best entry point to reach one target by passing through secondary target. It can be found by first orienting the needle to the targets from 2 arbitrary entry points

Needle placement for percutaneous procedures:
3 different approaches depending on the application

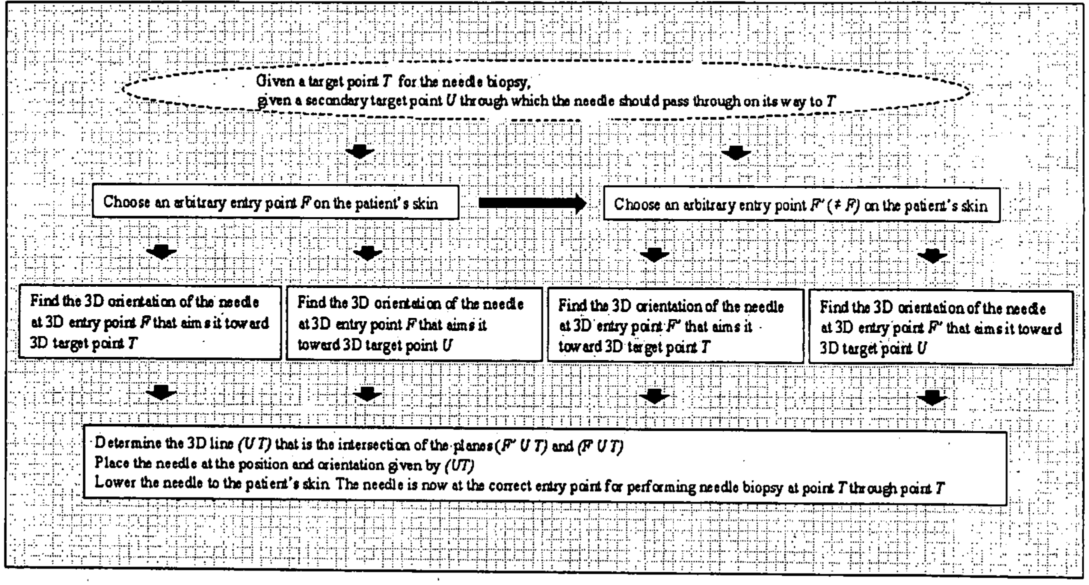
Given a target point T for the needle biopsy,
given a secondary target point U through which the needle should pass through on its way to T
Choose an arbitrary entry point F on the patient's skin
Choose an arbitrary entry point F' ($\neq F$) on the patient's skin
Find the 3D orientation of the needle at 3D entry point F that aims it toward 3D target point T
Find the 3D orientation of the needle at 3D entry point F that aims it toward 3D target point U
Find the 3D orientation of the needle at 3D entry point F' that aims it toward 3D target point T
Find the 3D orientation of the needle at 3D entry point F' that aims it toward 3D target point U
Determine the 3D line $(U\,T)$ that is the intersection of the planes $(F'\,U\,T)$ and $(F\,U\,T)$
Place the needle at the position and orientation given by (UT)
Lower the needle to the patient's skin The needle is now at the correct entry point for performing needle biopsy at point T through point T

Figure 5. Method for determining the best entry point for percutaneous procedures, given a primary target for the biopsy and a secondary target through which the needle must pass on its way to the primary target. This approach uses the method described in fig. 3 (see color coding in fig. 1).

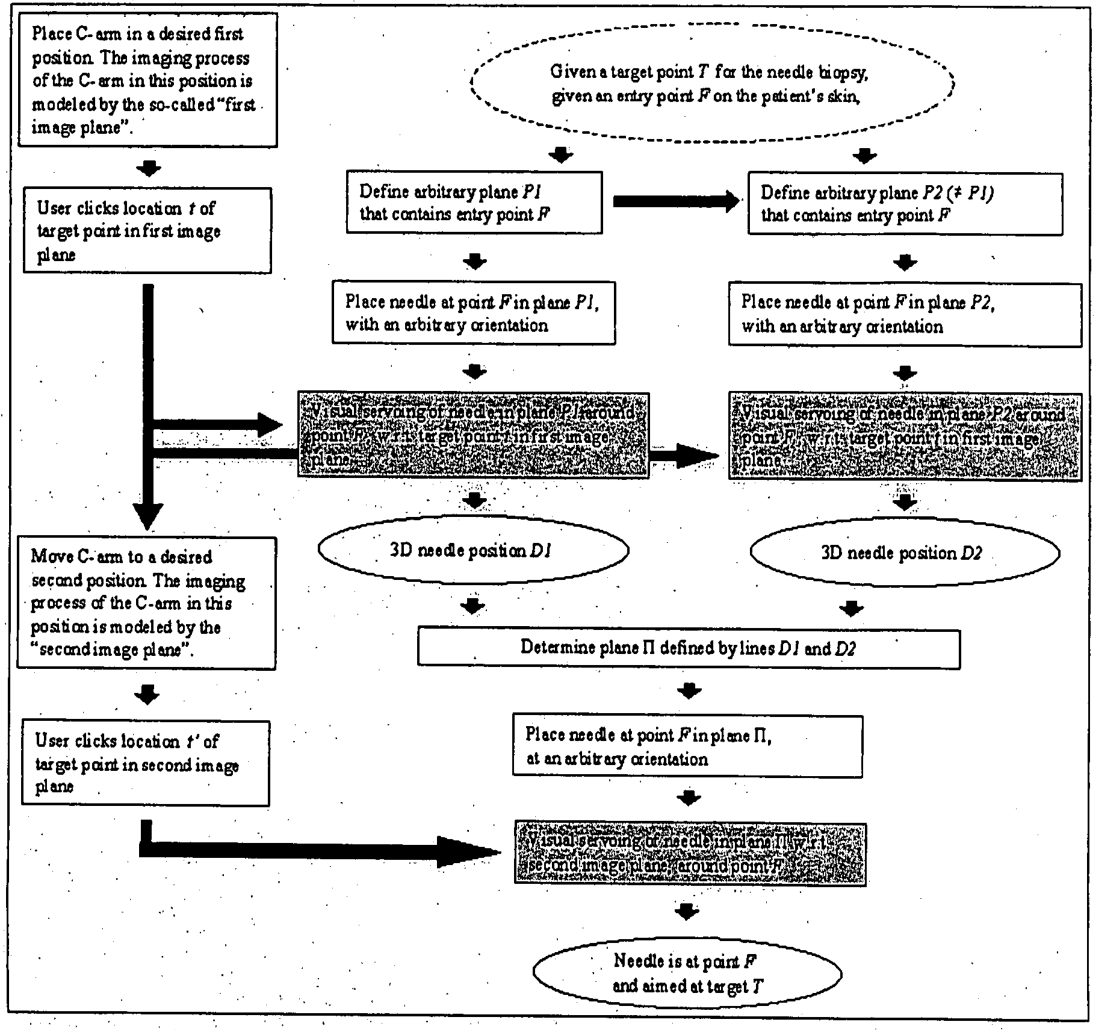
Place C-arm in a desired first position. The imaging process of the C-arm in this position is modeled by the so-called "first image plane".
User clicks location t of target point in first image plane
Move C-arm to a desired second position. The imaging process of the C-arm in this position is modeled by the "second image plane".
User clicks location t' of target point in second image plane
Given a target point T for the needle biopsy, given an entry point F on the patient's skin,
Define arbitrary plane P1 that contains entry point F
Define arbitrary plane P2 (≠ P1) that contains entry point F
Place needle at point F in plane P1, with an arbitrary orientation
Place needle at point F in plane P2, with an arbitrary orientation
Visual servoing of needle in plane P1 around point F, w.r.t. target point t in first image plane
Visual servoing of needle in plane P2 around point F, w.r.t. target point t in first image plane
3D needle position D1
3D needle position D2
Determine plane Π defined by lines D1 and D2
Place needle at point F in plane Π, at an arbitrary orientation
Visual servoing of needle in plane Π w.r.t. second image plane, around point F
Needle is at point F and aimed at target T

Figure 6. Method for positioning a biopsy needle from a given entry point to a given target. This approach uses the method described in fig. 4 (see color coding in fig. 1).

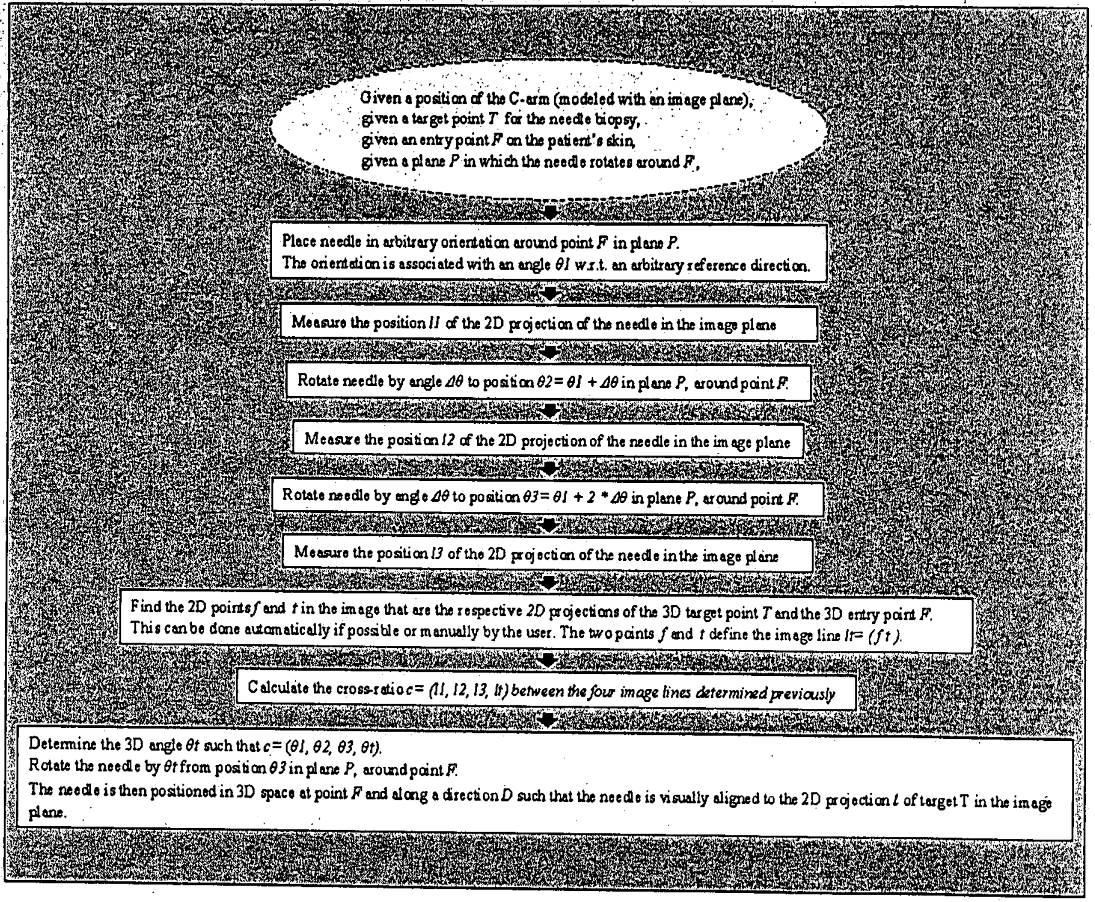
Given a position of the C-arm (modeled with an image plane), given a target point T for the needle biopsy, given an entry point F on the patient's skin, given a plane P in which the needle rotates around F,
Place needle in arbitrary orientation around point F in plane P. The orientation is associated with an angle $\theta 1$ w.r.t. an arbitrary reference direction.
Measure the position $l1$ of the 2D projection of the needle in the image plane
Rotate needle by angle $\Delta\theta$ to position $\theta 2 = \theta 1 + \Delta\theta$ in plane P, around point F.
Measure the position $l2$ of the 2D projection of the needle in the image plane
Rotate needle by angle $\Delta\theta$ to position $\theta 3 = \theta 1 + 2 * \Delta\theta$ in plane P, around point F.
Measure the position $l3$ of the 2D projection of the needle in the image plane
Find the 2D points f and t in the image that are the respective 2D projections of the 3D target point T and the 3D entry point F. This can be done automatically if possible or manually by the user. The two points f and t define the image line $lt = (f\,t)$.
Calculate the cross-ratio $c = (l1, l2, l3, lt)$ between the four image lines determined previously
Determine the 3D angle θt such that $c = (\theta 1, \theta 2, \theta 3, \theta t)$. Rotate the needle by θt from position $\theta 3$ in plane P, around point F. The needle is then positioned in 3D space at point F and along a direction D such that the needle is visually aligned to the 2D projection t of target T in the image plane.

Figure 7. Method for visual servoing of a needle in a plane in a fixed number of iterations. This approach is used in the previous approaches.